

"Compositions of polypeptides specific to pathogenic strains
and their use as vaccines and in immunotherapy "

The invention relates to new compositions of polypeptides specific to pathogenic strains, particularly to extra-intestinal *E. coli* strains.

5 It more particularly relates to combinations of antigenic polypeptides and combinations of antibodies directed against said polypeptides and to their use as vaccines and in immunotherapy, respectively.

Although *Escherichia coli* is probably the best known bacterial species and is one of the most common isolated in
10 clinical microbiology laboratories, misconceptions abound regarding the various types of *E. coli* and the infections they cause.

E. coli strains of biological significance to humans can be broadly classified in 3 major groups:

- 15 1. Commensal strains, which are part of the normal flora.
2. Intestinal pathogenic strains, which are not part of the normal flora. This group contains various pathotypes (EPEC, EHEC, ETEC, EIEC) not including *Shigella*.
3. Extra-intestinal strains (ExPEC) which are responsible
20 for infections outside the gastro-intestinal (GI) tract, but can also be part of the normal flora. All hosts, either immunocompromised or not are susceptible to these infections.

ExPEC strains are responsible for the majority of the urinary tract infections (UTI) particularly cystitis,
25 pyelonephritis, and catheter associated infections.

They are also responsible for abdominal infections, nosocomial pneumoniae, neonatal meningitidis, soft tissue infections, and bone infections. Each one of these localizations can lead to bacteremia with a risk of sepsis in
30 case of organ failure. ExPEC strains are indeed the most common Gram negative bacilli isolated from blood cultures.

750 000 cases of bacterial sepsis occur each year in the US, and are responsible for 225 000 deaths. In a recent study on 1690 cases of sepsis, it was shown that the main bacteria species identified is ExPEC (16% of the cases) and then *S.aureus* (14% of the cases).

These numbers demonstrate the importance of ExPEC strains in both hospital and community acquired infections.

ExPEC strains correspond to a homogenous subset of *E. coli* strains. Analysis of phylogenetic relationships among *E. coli* strains by MLEE has revealed that *E. coli* belong to 4 main phylogenetic groups designated A, B1, B2 and D.

The pathogenesis of ExPEC strains is that of extra-cellular microorganisms, i.e., they are well adapted to growth in the extra-cellular fluids and efficiently resist phagocytosis by polymorphonuclear. Initial studies have shown that virulence factors known to be important for the extra-cellular growth are mainly found in B2/D *E. coli*., thus suggesting that B2/D subgroups contain most of the ExPEC strains. This was reinforced by experiments performed on animals showing that B2/D strains are more virulent than A and B1 strains. Subsequent epidemiological studies have indeed confirmed these hypotheses. B2/D isolates are those predominantly responsible for neonatal meningitidis (87%) and community or nosocomial acquired urosepsis, (93% and 85%, respectively).

Similar results have been reported for cystitis (70% are due to the sole B2 *E. coli*), thus demonstrating that the importance of ExPEC strains.

These recent findings demonstrate that the B2/D subgroup of strains is the *E. coli* core genome the best adapted to growth in extra-cellular fluids.

In addition to this core genome, ExPEC strains have various pathogenicity islands which encode virulence factors

associated with the different pathogenesis of extra-intestinal *E. coli* infections (UTI, urosepsis, neonatal meningitidis...). Among the main virulence factors are the capsule, which is well-known to be important for extra-cellular growth, and the iron chelation systems (aerobactin and enterochelin, for example). In addition, depending on the pathogenesis, these strains can produce toxins (CNF, hemolysin...), adhesins (pap, sfa...) and other iron chelation systems.

The notion that B2/D *E. coli* correspond to a distinct subset of pathogenic *E. coli* strains is reinforced by the fact that B2/D *E. coli* are not broadly isolated from the stools of humans. They were recovered from only 11% of individuals, whereas A and B1 subgroups are present in the stools of 74% of the individuals of a human population.

As mentioned above the pathogenesis of ExPEC strains relies on their ability to multiply in the extra-cellular fluids and to resist bactericidal activity of the complement and phagocytosis by polymorphonuclear. Therefore, as for other extra-cellular pathogens (*Haemophilus influenzae*, *Streptococcus pneumoniae* and *Neisseria meningitidis*) a protective antigen against ExPEC has to induce antibodies that promote opsonisation and/or the bactericidal activity of serum.

Considering the above statements, an efficient antigen has to be largely represented among the population of B2/D *E. coli*.

Similarly to other extra-cellular pathogens, the capsular polysaccharide would be an ideal antigen, however most pathogenic B2 strains express the K1 polysaccharide. The latter has a structure identical to that of group B meningococcus, which is non-immunogenic and shares common antigens with the brain. Another possible target may be the lipopolysaccharide (LPS). However there are a large number of different LPS serotypes that are shared by various subgroups.

The inventors have now found that some specific compositions of polypeptides coded by the B2/D genome, but absent from A and B1 *E. coli* strains, are particularly useful as antigens and can specifically prevent the pathologies due to ExPEC strains. Homologs of these antigenic components can be found in other pathogenic bacterial species and therefore are useful to prevent the pathologies caused by these bacteria. Accordingly, any reference to products specific to ExPEC strains and to their uses will encompass components in these species.

For example homologous antigens could be present in the following species and be as such used for prevention of disease due to the bacteria:

Pseudomonas aeruginosa, *Escherichia coli* O157:H7, *Yersinia pestis*, *Vibrio cholerae*, *Legionella pneumophila*, *Salmonella enterica*, *Salmonella typhimurium*, *Haemophilus influenzae*, *Neisseria meningitidis*, *Neisseria gonorrhoeae*,

Bacillus anthracis, *Burkholderia cepacia*, *Campylobacter jejuni*, *Chlamydia pneumoniae*, *Chlamydia trachomatis*, *Clostridium botulinum*, *Clostridium difficile*, *Cryptococcus neoformans*, *Enterobacter cloacae*, *Enterococcus faecalis*, *Helicobacter pylori*, *Klebsiella pneumoniae*, *Mycobacterium leprae*, *Mycobacterium tuberculosis*, *Pseudomonas aeruginosa*, *Salmonella paratyphi*, *Salmonella typhi*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Listeria monocytogenes*, *Moxarella catarrhalis*, *Shigella dysenteriae*, *Shigella flexneri*, *Shigella sonnei*, *Staphylococcus epidermidis*, *Streptococcus pneumoniae*, and any species falling within the genera of any of the above species.

It is then an object of the invention to provide new combinations of isolated antigenic polypeptides, and new combinations of isolated polynucleotides belonging to the core B2/D genome and not present in commensal *E. coli*.

Another object of the invention is to provide new combinations of antibodies raised against the antigenic polypeptides of said combinations, or peptidic fragments thereof.

5 It is still another object of the invention to provide vectors and host cells containing said polynucleotides.

Another object of the invention is to provide vaccine compositions specific to extra intestinal infections caused by ExPEC and pathologies caused by other pathogenic strains
10 expressing antigenic polypeptides homologous to the ExPEC antigenic polypeptides.

The invention also relates to means for detecting and treating a development of *E. coli* in a human or animal compartment which is extra-intestinal (systemic and non-
15 diarrhoeal infections, such as septicaemia, pyelonephritis, or meningitis in the newborn).

The combinations of isolated antigenic polypeptides used according to the invention are selected among polypeptides specific to B2/D *E. coli* strains and not present in A and B1
20 isolates of *E. coli*. They are encoded by genes belonging to the core B2/D genome and are not present in commensal *E. coli*.

They comprise at least one polypeptide of a first group, having a sequence selected in the group comprising the sequences of SEQ ID N° 1 to N° 66 or 133-145 and at least one
25 peptide of a second group, having SEQ ID N° 159, or homologous sequences of polypeptides of the first group and/or the second group with a minimum of 25% of identity with the whole sequences of said polypeptides.

Preferred compositions comprise combinations with the
30 polypeptide of the second group having SEQ ID N° 159.

Others preferred compositions comprise combinations wherein the polypeptides of the first group have a sequence selected in the group comprising SEQ ID N° 14, 15, 17, 21, 22,

23, 28, 29, 30, 32, 36, 38, 39, 41-44, 46, 49, 50, 52 to 55, 58, 60, 63, 133-138.

Other preferred compositions comprise the polypeptide having SEQ ID N° 159 and a polypeptide selected in the group comprising peptides having sequences SEQ ID N° 2, 26, 28, 36, 34, 134, 141 and 145.

The above-mentioned polypeptides of the first group and the polynucleotides coding for said polypeptides are disclosed in WO 03/074553 in the name of Mutabilis SA.

10 The polypeptide of SEQ ID N° 159 and the polynucleotides having SEQ ID N° 160 coding for said polypeptides are disclosed in WO 0121636 in the name of New-York University.

The invention also relates to combinations wherein said homologous isolated antigenic polypeptides of the first group have at least 25% identity to a polypeptide having a sequence SEQ ID N° as above defined, more particularly having SEQ ID N° 14, 15, 17, 21, 22, 23, 28, 29, 30, 32, 36, 38, 39, 41-44, 46, 49, 50, 52 to 55, 58, 60, 63, 133-138, or at least 25% identity to a fragment comprising at least 5, at least 10, at least 20, at least 30, at least 40, at least 50, at least 60 or more than 60 consecutive amino acids of a polypeptide having a sequence corresponding to said SEQ ID N°s, as determined using BLASTP or BLASTX with the default parameters.

25 The invention also relates to combinations comprising homologous isolated antigenic peptides of second group having at least 25% identity to a polypeptide having SEQ ID N° 159.

The invention also relates to the use in combination of isolated polynucleotides coding for a polypeptide of the first group and of isolated polynucleotides coding for polypeptides a polypeptide of the second group such as above defined according to the universal genetic code and taking into account the degeneracy of this code. The term "polynucleotide" encompasses any nucleotidic sequence such as DNA, including cDNA, RNA, including mRNA.

The polynucleotides coding for the polypeptides of the first group have preferably sequences corresponding to SEQ ID N° 67 to SEQ ID N° 132 or 146 to 158 and are in combination with polynucleotide having SEQ ID N° 160.

5 More preferably, said polynucleotides have sequences corresponding to SEQ ID N° 80, 81, 83, 87, 88, 89, 94, 95, 96, 98, 102, 104, 105, 107-110, 112, 115, 116, 118, 119, 126, 127, 130, 132, 135, 146-151 and are in combination with polynucleotides having SEQ ID N° 160.

10 Other preferred combinations comprise polynucleotides having polynucleotides having SEQ ID N° 68, 92, 89, 94, 100, 154, 147 and 146 in combination with the polynucleotide having SEQ ID N° 160.

The polynucleotides coding for the polypeptides of the
15 second group have preferably sequence SEQ ID N° 160.

The invention also relates to combinations of homologs to said polynucleotides. Said homologs may have at least 25% identity to a polynucleotide having said sequences, or at least 25% identity to a fragment comprising at least 15, at
20 least 30, at least 60, at least 90, at least 120, at least 150, at least 180 or more than 180 consecutive nucleotide of a polynucleotide having one of said SEQ ID N°s, as determined using BLASTN with the default parameters, and are encompassed by the invention inasmuch as they are capable of coding for a
25 polypeptide having the antigenic properties of those according to the invention.

The present application is also aimed towards any expression vector comprising at least one isolated polynucleotides coding for a polypeptide of said first group
30 and at least one polynucleotide coding for a polypeptide of said second group according to the universal genetic code and taking into account the degeneracy of this code. The term "polynucleotide" encompasses any nucleotidic sequence such as DNA, including cDNA, RNA, including mRNA.

Preferred vectors comprise polynucleotides coding for the polypeptides of the first group having preferably sequences corresponding to SEQ ID N° 77 to SEQ ID N° 132 or 146 to 158.

More preferred vectors comprise, polynucleotides having
5 sequences corresponding to SEQ ID N° 80, 81, 83, 87, 88, 89, 94, 95, 96, 98, 102, 104, 105, 107-110, 112, 115, 116, 118, 119, 126, 127, 130, 132, 135, 146-151.

More preferred vectors further comprise polynucleotides coding for the polypeptides of the second group having
10 sequence SEQ ID N° 160.

Other preferred expression vectors comprise polynucleotides having SEQ ID N° 68, 92, 89, 94, 100, 154, 147 and 146 in combination with the polynucleotide having SEQ ID N° 160.

15 Said vectors may also comprise homologs to said polynucleotides. Said homologs may have at least 25% identity to a polynucleotide having said sequences, or at least 25% identity to a fragment comprising at least 15, at least 30, at least 60, at least 90, at least 120, at least 150, at least
20 180 or more than 180 consecutive nucleotide of a polynucleotide having one of said SEQ ID N°s, as determined using BLASTN with the default parameters, and are encompassed by the invention inasmuch as they are capable of coding for a polypeptide having the antigenic properties of those according
25 to the invention.

The invention also relates to any cell transformed by genetic engineering, characterized in that it comprises, by transfection, at least one of polynucleotides coding for a polypeptide of said first group and at least one a
30 polynucleotide coding for a polypeptide of said second group and/or at least one vector according to the invention, and/or in that said transformation induces the production by this cell of said polypeptides.

The combinations of said antigenic polypeptides are capable of inducing an antibody response for prevention of infections due to ExPEC strains regardless of the pathogenesis and of the infection site (UTI, pyelonephritis, sepsis, bacteremia, neonatal meningitis).

The invention thus relates to vaccine compositions specific to *E. coli* extra-intestinal infections, comprising an effective amount of at least one antigenic polypeptide or fragment thereof of said first group and at least one antigenic polypeptide or fragment thereof of the second group, with a carrier, particularly at least one polypeptide of SEQ ID N° 1 to SEQ ID N° 66 and 133-145 and the homologous polypeptides, and at least one polypeptide of SEQ ID N° 159.

Such vaccine compositions are particularly useful for preventing urinary system infections, pyelonephritis, sepsis, bacteremia, neonatal meningitis.

The vaccine compositions of the invention are indicated for:

- Immunodepressed patients, ideally before the start of the immunosuppressive therapy: patients suffering from cancer, diabetes, leukemia, transplant patients, patients receiving long-term steroids therapy.
- Patients before surgery where there is a high risk of *E. coli* infections (abdominal surgery).
- In all these cases, the *E. coli* vaccine of the invention could be administered in association with a *Staphylococcus aureus* vaccine or a group B *Streptococcus* vaccine,
- Patients with recurrent UTI, especially after one episode of pyelonephritis,
- The prevention of neonatal infections will require vaccination of the mother, implying vaccination long before pregnancy to avoid potential problem. Ideally such a vaccine should be associated with a Group B *Streptococcus* polysaccharide vaccine in order to also

prevent late onset neonatal infections. It should be pointed out that the induction of a level of antibodies against B2/D *E. coli* in pregnant women would also prevent UTI, which are always a risk in the context of a pregnancy.

The formulation and the dose of said vaccine compositions can be developed and adjusted by those skilled in the art as a function of the indication targeted, of the method of administration desired, and of the patient under consideration (age, weight).

These compositions comprise one or more physiologically inert vehicles, and in particular any excipient suitable for the

For example the vaccine could be a suspension of the purified polypeptide in sterile water with aluminum based mineral salt as adjuvant and be administered subcutaneously with a first and boosting injection.

The combinations of antibodies respectively raised against at least one polypeptide of said first group and at least one polypeptide of said second group are also part of the invention.

They are capable of binding to said polypeptides in physiological-type conditions (*in vivo* or mimicking *in vivo*) when administered to a human or animal organism, and ELISA-type conditions when said binding product is intended to be used in assays and methods *in vitro*. Such combinations of antibodies advantageously inhibit the extra-intestinal growth of ExPEX strains in human or animal.

The invention thus relates to pharmaceutical compositions comprising an effective amount of a combination of antibodies such as above defined.

Such pharmaceutical compositions are particularly useful for immunotherapy applications for treatment and prevention of severe infections in at risk populations such as neonates or

patients undergoing surgical procedures, or having urinary tract infections to prevent septicemia. For these applications specific human monoclonal antibody (Mab) will be derived from said peptides or polypeptides.

5 . Such pharmaceutical compositions comprising an effective amount of a combination of antibodies such as above defined are also useful for treating neonatal infections, in association with antibodies against *Staphylococcus aureus* and/or antibodies against group B *Streptococcus*.

10 The methods for manufacturing such antibodies using the polypeptides of the combinations according to the invention are available to those skilled in the art. They are conventional methods which comprise, in particular, the immunization of animals such as rabbits and the harvesting of
15 the serum produced, followed optionally by the purification of the serum obtained. A technique suitable for the production of monoclonal antibodies is that of Köhler and Milstein (Nature 1975, 256:495-497).

Said antibodies do not recognize the cells of the human or
20 animal to which it is intended.

The antibodies or fragments thereof are advantageously humanized when intended for a human administration.

Alternatively, humanized Mab could be derived from murine or rat Mab specific of the antigen. These fully humanized Mab
25 are constructed using conventional molecular techniques to graft complementarity-determining regions from the parent murine or rat antibacterial antibody into human IgG1 kappa heavy and light-chain frameworks.

The present invention is also aimed towards the use of
30 said combinations of at least one polypeptide of the first group, particularly having SEQ ID N° 14, 15, 17, 21, 22, 23, 28, 29, 30, 32, 36, 38, 39, 41-44, 46, 49, 50, 52 to 55, 58, 60, 63, 133-138, and one polypeptide of the second group, particularly having SEQ ID N° 159, said antibodies raised

against said polypeptides, or polynucleotides coding for said polypeptides for the diagnosis of the presence or absence of undesirable extra-intestinal *E. coli*, and/or for the diagnosis of an extra-intestinal *E. coli* infection.

5 The invention particularly relates to the use of said combinations of at least one polypeptide having SEQ ID N° 14, 15, 17, 21, 22, 23, 28, 29, 30, 32, 36, 38, 39, 41-44, 46, 49, 50, 52 to 55, 58, 60, 63 or 133-138, and polypeptide having SEQ ID N° 159, and use of antibodies raised against said
10 polypeptides, or the use of polynucleotides coding for said polypeptides for the diagnosis of the presence or absence of undesirable extra-intestinal *E. coli*, and/or for the diagnosis of an extra-intestinal *E. coli* infection.

 The invention also relates to the use of combinations of
15 polypeptides comprising polypeptide having sequence SEQ ID N° 159 and at least one polypeptide selected in the group comprising peptides having sequence SEQ ID N° 2, 26, 28, 36, 34, 134, 141 and 145.

 The detection of the presence or absence of such compounds
20 can in particular be carried out by nucleotide hybridization, by PCR amplification or by detection of their polypeptide products. Detection of the presence of such compounds makes it possible to conclude that a B2/D *E. coli* strain is present.

 The invention also relates to pharmaceutical compositions
25 for alleviating and/or preventing and/or treating an undesirable growth of *E. coli* comprising an effective amount of at least one polypeptide of said each group particularly having SEQ ID N° 1-66 to 133-145, for the first group, and SEQ ID N° 159 for the second group, in combination with a
30 pharmaceutically acceptable carrier.

 Preferred pharmaceutical compositions comprise at least one polypeptide having SEQ ID N° 14, 15, 17, 21, 22, 23, 28, 29, 30, 32, 36, 38, 39, 41-44, 46, 49, 50, 52 to 55, 58, 60,

63, 133-138, and at least one polypeptide having SEQ ID N° 159.

Other preferred pharmaceutical compositions comprise at least one polypeptide having SEQ ID N° 2, 26, 28, 36, 34, 134, 141 and 145 and polypeptide having SEQ ID N° 159.

The present application is also aimed towards any use of a said combination of polypeptides such as above defined for the manufacture of a composition, in particular of a pharmaceutical composition, intended to alleviate and/or to prevent and/or to treat an undesirable growth of *E. coli*, such as an *E. coli* infection, (for example systemic and non-diarrhoeal infections), the presence of extra-intestinal *E. coli* or a sanitary contamination.

The present invention is illustrated by the examples, which follow and which are given in a non limiting capacity. In said examples, it is referred to Figure 1 which represents histograms of the results showing an increase of survival in the animals vaccinated with polypeptides combinations.

Examples of vaccination to demonstrate immunogenicity of polypeptides:

Example 1: Preparation of antigenic peptidic combinations

A polypeptide having SEQ ID N° 28 is purified from an *E. coli* strain or from a host cell containing a recombinant expression plasmide.

Polypeptides having SEQ ID N° 28 and SEQ ID N° 159, respectively, are purified and conjugated with a toxin.

A physiologically inert carrier is added to the preparation, which is sterilized and can be injected parenterally, subcutaneously or intramuscularly.

Said composition can also be sprayed onto mucosa with the aid of a spray.

Said combination of polypeptides may be added to a childhood vaccine.

Protecting effect of said combination in mice infected by *E. coli*

5 A total of 100 µg of said purified combination of polypeptides was administered to Balb C mice according to usual procedure of immunization.

A decrease of mortality in immunized animals was observed compared to non-immunized animals.

Example 2:

10 Example of antigens combination to induce an immune response that protects mice after experimental challenge with a pathogenic strain of *E.coli* (ExPEC):

Experimental protocol:

15 - Balb/c mice, female, 6 weeks old were immunized on day 1 by subcutaneous injection of a solution containing a combination of two purified polypeptides (20 micrograms of each) and Complete Freund's adjuvant (CFA) in PBS, and control mice were injected with CFA in PBS buffer.

20 - 3 weeks later a boost injection of the same combination of polypeptides in solution (10 micrograms of each) with the incomplete Freund's adjuvant was performed.

Before challenge on day 42, sera was collected on day 41 to analyze the antibody response in the vaccinated animals:

25 - WB analysis of sera from immunized mice were performed to detect the antibody response to the recombinant protein used for immunization as described above.

- An ELISA assay was used to measure polypeptides specific antibody titres obtained in vaccinated animals:

30 Experimental challenge to measure protection induced by antigens combination:

On day 42, vaccinated and control mice were challenged with an *E.coli* ExPEC virulent strain belonging to B2 group at a dose equal to the LD 50 (5.10^5 cfu/mice) by intraperitoneal injection. The end point of the assay was the survival to the

lethal challenge. Mortality observed in each group of animals was recorded at 48h and 120h. The results are shown in Table 1 are expressed as a percentage of survival in the vaccine group versus the control mice group.

5 Table 1: Protection obtained in mice challenged after immunization with combination of polypeptides encoded by the corresponding ORFs.

Combination of two polypeptides SEQ ID / SEQ ID polypeptide 1 polypeptide 2	% Survival at 48 h (nb of mice alive/nb total)		% Survival at 120h (nb of mice alive/nb total)	
	Vaccine	Control	Vaccine	Control
159 / 2	64 (9/14)	44 (7/16)	64 (9/14)	38 (6/16)
159 / 34	36 (5/14)	25 (4/16)	36 (5/14)	25 (4/16)
159 / 145	86 (12/14)	44 (7/16)	86 (12/14)	38 (6/16)

Figure 1 represents histograms of the results and shows an increase of survival in the animals vaccinated with polypeptides combinations according to the invention.